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MARS '94 SMALL STATION/PLUTO FAST FLYBY TRIAXIAL MAGNETOMETER

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ABSTRACT

We describe a small weight and low power magnetometer which was designed and built for the Mars '94 mission. A similar design could easily fit on the Pluto Fast Flyby spacecraft with minimal request of spacecraft resources with a substantial gain in science.

1. introduction

The principle of operation of each component of the three-component magnetometer resembles that of the well-known fluxgate magnetometer: A highly permeable core is alternately saturated by a strong magnetic field in both preferential directions of magnetization. In a pick-up coil surrounding the core, an alternating voltage is thus induced. In the absence of external magnetic fields, this a.c. voltage will consist only of odd-numbered frequency components of the fundamental wave. If the system is exposed to an additional external magnetic field, even-numbered harmonics will also appear in the induced voltage. They are largely proportional to the external field, and they may be detected. The proportionality can be improved considerably by applying the principle of inverse feedback.

11. Probes

Contrary to the bar magnetic cores of fluxgate magnetometers, the one described here uses toroidal cores. Such cores arc used very successfully particularly in space magnetometer experiments (projects: MAGSAT [Acuna et al. 1978], G101''1'O [Neubauer et al. 1986]). They have the advantages of a greater sensitivity, a lower zero-point drift, and lower noise. Because of their closed magnetic circuit, they require less excitor power than the strongly sheared bar cores. This means that they arc more easily saturated. 1 'irst references to magnetometer of this type can alread y be found in Aschenbrenner and Goubau [1935]. They used florist's wire for their magnetic core! For the wide temperature range application desired for Mars '94 and Pluto Fast Flyby, nickel molybdenum permalloy cores with a diameter of 0.625" and a Curie temperature of about 465° C were chosen.

The cores, which arc equipped with a magnetization coil (excitor coil), arc surrounded by the actual pick-up coils (measurements coils), which arc flat rectangular coils. The latter consist of a thin-walled MACOR coil form, which supports the winding of enamel-coated copper wire. The temperature coefficient of MACOR (about 10 ppm) is about equal to that of the toroidal cores, so that even considerable temperature variations will not result in mechanical stresses.

Because the magnetometer is operated in the inverse feedback mode, each of these coils has dual functions: on one hand, it is used to detect the induced voltage, on the other hand, to compensate the (magnetic) field in its interior (in the direction of its axis). Therefore the magnetic toroidal cores operate in a near-zero field. 'l"his cause the output signal, which is proportional to the field, to be linear over a wide measuring range. Conversely, by the inverse feedback the temperature stability of the instrument is mainly attributed to the mechanical stability of these coils.

Each one of these units of toroidal core with pick-up coil is a magnetic probe, the measuring axis of which is identical with the longitudinal axis of the coil. To measure the three dimensional magnetic field vector, three such units arc required. They arc mounted orthogonally to each other on a LEXAN support. Because of the inevitable extent of the individual probes, they can only be mounted with spatial displacements. The components arc spaced approximately 22 mm from each other.

1.2 Magnetometer Electronics

The Mars '94 magnetometer electronics are quite similar to those of other space mission fluxgate circuitries. The main design goals were lowest power consumption, and lowest possible mass, and wide temperature range (-100 to + 150” C).

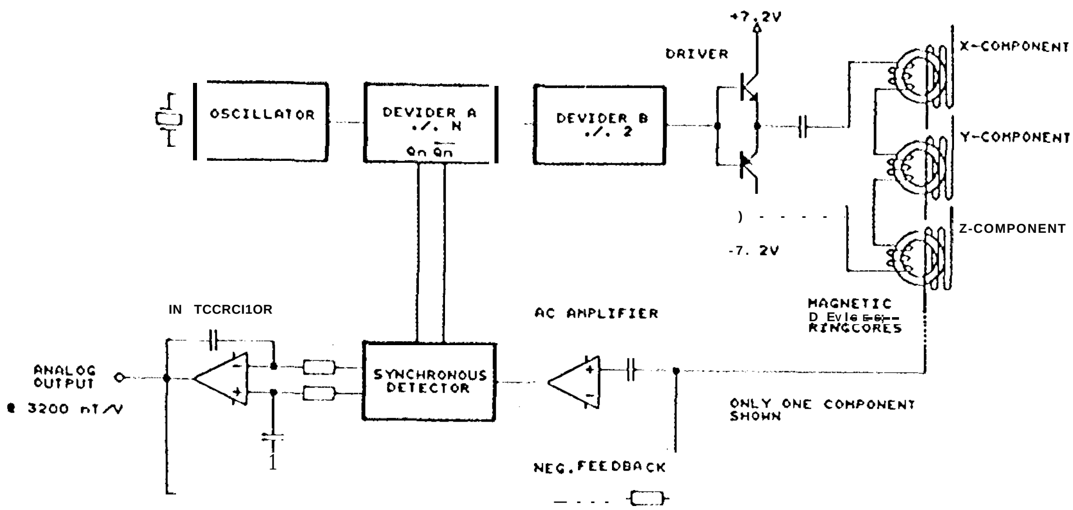

Fig. 1 Block diagram of the MARS '94 magnetometer electronics; only one component of the sensor electronics shown.

1.2.1 Exciter Circuit

The exciter circuit provides the periodic magnetization and demagnetization of the toroidal cores. The exciter frequency chosen in our case, 8 kcps, is generated by a quartz oscillator with subsequent divider stage. At the same time, the control signal with the double frequency 2f as needed for the synchronous rectifiers (located on the analog boards) is obtained from this divider stage. For the exact adjustment of the working point of the rectifier, a digital phase shifter is provided.

The magnetizing current is supplied by a complementary transistor-exciter-inductivity and a capacity in parallel with the inductivities of the toroidal cores, which are connected in series, a very efficient stimulation circuit may be realized: the additional inductivity prevents high current peak at the exciter circuit and also decouples it from the magnetic circuits, so that the circuit capacitor is periodically charged. When the voltage at the capacitor reaches a level at which the exciter current begins to saturate the toroidal cores, the resulting sudden reduction of the inductivities effects a corresponding decrease in the inductive resistances. The capacitor is now instantaneously discharged via the exciter coils of the toroidal cores. This causes current peaks of up to 250 milliamps and more in this circuit, which produce magnetization field intensities far above the saturation field intensity of the core material. The exciter circuit is not affected by this, its input current is lower by at least one order of magnitude.

1.2.2 Analog Circuit(s)

The analog circuit for each component of the magnetic field produces an output signal that is proportional to the magnetic field to be measured. As explained above, for this purpose the 2f alternating voltage component of the voltage induced in the pick-up coil is used. At first the induced voltage is amplified, then it is rectified synchronously with twice the exciting frequency.

Besides their function as rectifiers, synchronous detectors have a properly that is very desired in our case: they act as narrow-band filters at their operation frequency. The band-width is essentially determined by the cutoff frequency of the subsequent low-pass filter, in this case an active integrator.

The stages described so far already establish a complete magnetometer with non-inverse feed-back, i.e., at the output of the integrator, a voltage proportional to the magnetic field is available.

The inverse feedback operational mode of the magnetometers is effected by a suitable return circuit of a current proportional to the output voltage to the pick-up coil. To keep the power consumption low, the amount of active electronic devices was lowered to the absolute minimum. That is why the voltage to current conversion is performed by an ordinary resistor instead of an additional current source (operational amplifier), rsp. three of those. Without the current source it is impossible to achieve active temperature compensation of each sensor's sensitivity by a negative impedance converter circuitry (NIC). But the decision was supported by the results of measurements of the sensitivity's temperature dependency. The measured drift is in the range of 0.2-0.08 nT/K [G. Clerc, internal report and private communication, 1992].

2. Boom

To achieve an almost magnetically clean environment during operation, the sensor head has to be moved away from the spacecraft as fare as possible. This will be performed by a two-times folded boom. This is shown in Figure 2. With respect to mass and stiffness, the boom will be made out of carbon fiber tubes, which are filled with styrofoam. The forces for releasing or opening the boom will be delivered by nonmagnetic springs.

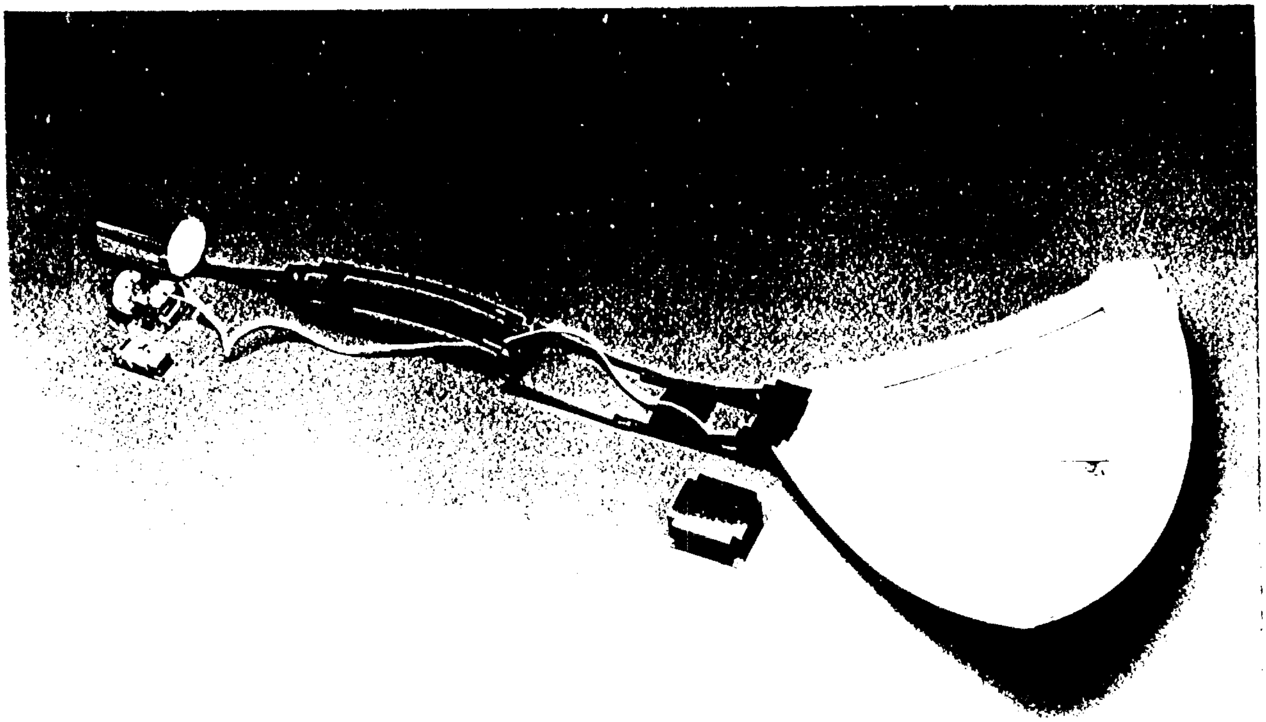

Fig. 2 The triaxial magnetometer (left end), boom and electronics.

Due to the lack of precise drawings or, a lot better, a model of one of the four petals, covering the upper part of the Small Station, the development of the boom is not yet finished. The attached two drawings should be regarded as preliminary ones only.

3. Pluto Fast Flyby

For the Pluto mission we propose to use either a short carbon fiber boom, such as on Giotto. The mass of a 2 meter boom is 150 g.

4. Acknowledgements

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5. Bibliography

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4 Appendix

4.1 *Technical Data*

• Mechanical Items: Sensor Head

Sensor head dimensions	: 29 * 29 * 55 mm^3 [w * h * l]
Housing tube diameter	:47 mm
Housing tube length	: approx. 75 mm (depending on inclinometer(sd)!)
Thickness of damping material	:9 mm
Outer diameter of sensor head	:65 mm (incl. damping material)
length of sensor head	:95 mm (incl. damping material)
Material of sensor coil support	: MASCOR-structure
Magnetic material of sensors	: Nickel molybdenum permalloy, toroidal shaped cores
Material of sensor support	: I,l~XAN-structure
Damping material	: ROHACEL.1.
Mass of sensor head	: 35 g
Total mass of sensor head	: 118 g

• Mechanical Items: Magnetometer Electronics

Dimensions of the box	:64 * 75 * 40 mm^3 [w * l * h]
Material of the box	: aluminum
Mass of electronic box	: 140 g

• Electrical Items: Magnetometer

Measuring range (each axis)	: ± 8000 nT
Output voltage swing	: ± 2.5 V
Bandwidth (-3dB)	:70117.
Thermal drift	: < 0.2 nT/K (each component)
Noise	:< 0.5 $nT_{p\text{-}p}$
Power supply	:5 5.0V, 8mA (may be switched)
Power supply	: + 15.0V, 1.6mA (permanent)
Power consumption	:<120 mW (continuous operation)

- Mechanical Items: Boom

Type	: two times folded, twin arm boom
Material	: carbon fiber
Length	: approx. 1000 mm
Mass of boom (without springs)	: 85 g
Mass of springs	: approx. 20 g (estimated)